International Journal of Mechanical and Production
Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 9, Issue 2, Apr 2019, 645-648




# TEST SECTION BLOCKAGE CORRECTIONS FOR SUBSONIC OPEN-CIRCUIT WIND TUNNEL

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***ABSTRACT***

***By their very nature, even the most perfect wind tunnels cannot produce an unconstrained flow past a model. The problem of blockage in the test section has been of concern to experimentalists and theoreticians in the study of model shapes, wind tunnel design and experimental techniques over the years. This Blockage arises mainly due to the tunnel-wall interference. The foundation of research on tunnel-wall interference is attributed to Prandtl because his lifting-line theory, led to many experimental investigations with the object of verifying the theory. The interference due to the wall contributes to different types of blockages in the test section. Therefore, modifications are required so that the test results similar to those of the actual conditions.***

***This paper will touch upon different types of blockage effects and the corrective methods to be used.***

***KEYWORDS: Test-Section, Buoyancy, Boundary layer, Solid Blockage, Wake Blockage & Wall Correction***

**Received:** Jan 23, 2019; **Accepted:** Feb 13, 2019; **Published:** Mar 22, 2019; **Paper Id.:** IJMPERDAPR201964

Original Article

## 1. INTRODUCTION

Since the test section of the wind tunnel is of a confined volume, the aerodynamicquantities acquired, do not bear a resemblance to those obtained from an infinitely spaced boundaries, like in the situation of an aircraft flying in the sky. Severalmethodsare used to study the airflow around the test body and relate it with theoretical results. A wall-interference correction is one of the most significant methods to be considered, for a wind tunnel to give an error free measurement of the in-air situation, where, there is no constraint to the flow around an aircraft. A substantiated correction method should lead to an improvement in the accuracy of data obtained from wind tunnel studies. For a wind tunnel data to fine-tune the unconstrained values, variety of empirical and theoretical methods have been used; but the scrutiny of these techniques specify that the proportions of the adjustments may vary by more than a factor of four provided by them to a given test geometry (Closed Test Section Wind Tunnel Blockage Corrections for Road Vehicles; Glauert, 1933). The cause of this variation is due to the application of the correction methods for different type of bodies, ranging from configurations of streamline aeronautical to those that have a consequential domain of flow separation.

## 2. DATA CORRECTION METHODS

The effect of these blockages can be categorized into the following components:

- Buoyancy

- Solid Blockage
- Wake blockage

### 2.1 Buoyancy

Due to the increase in thickness of the boundary layer on the walls of the test section as it progresses towards the end, almost all wind tunnels have a variation in static pressure along the test section in the direction of the flow. This expansion of the boundary layer results in a reduction of the jet area which increases the local velocity in the test section along its longitudinal axis. As the endapproaches, the pressure is observed to be more negative than upstream. This cause the model to be drawn downstream. In short, different sections of the test-section will experience different local velocity.

The amount of horizontal buoyancy is usually insignificant for wings, but for fuselages and nacelles it is larger and becomes important.

The correction, given by Glauert (Glauert, 1933) (Maskell, 1965) for buoyancy is as follows

$$\Delta D_b = -\frac{\pi}{4}\lambda 3 t^3 \frac{dp}{dl}$$

$\lambda_3 =$ body shape factor for three-dimensional bodies(Pope, Rae,Jr, & Barlow, 1999)

t = maximum body thickness

Another solution to avoid error due to Buoyancy is to construct a test section with slightly increasing cross-sectional area to compensate for the decreasing effective jet area.

### 2.2 Solid Blockage

The ratio of the frontal area of an object to the stream cross-sectional area is effectively zero in actual operations. In wind tunnel test conditions, this ratio reflects the relative size of the body to be tested and the test section. Solid Blockage is the characteristic of the blockage (object being tested) volume and the wake bubble created next to it. Due to an effective reduction in the area available for the flow, the flow speed in this region of the wind tunnel test section increases relatively with respect to the free stream velocity. Correspondingly, the pressure decreases with respect to initial entry pressure.

For a scaled-down model, the increase in velocity due to solid blockage is comparatively small than that calculated from a direct reduction of area as the streamlines near the tunnel walls are displaced more than those near the model (Pope, Rae, Jr, & Barlow, 1999). Solid blockage is responsible for the increase in all forces and moments, as it initially increases the dynamic pressure. (Pope, Rae, Jr, & Barlow, 1999). This could produce erroneous results if not accounted for.

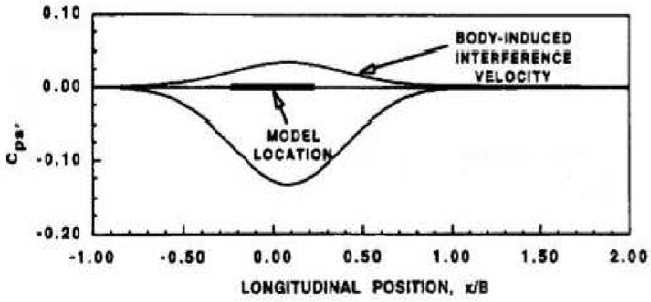


**Figure 1: Pressure Distribution in a Test Section due to Solid Blockage**

According to Herriot, the body is represented by a source-sink distribution and is contained in the tunnel walls by an infinite distribution of images (Pope, Rae,Jr, & Barlow, 1999). Upon summing up of the images we get,

$$\varepsilon_{sb,w} = \frac{k_3.\tau.(wing\ volume)}{C^{3/2}}$$

$K_3$ = Body shape factor

τ = factor depending on the tunnel test-section shape and model span-to-tunnel-width ratio

Thom modified this equation for any three-dimensional body,

$$\varepsilon_{sb} = \frac{k.(model\ volume)}{C^{3/2}}$$

K = 0.9 for a 3-d wing and 0.96 for a body of revolution

### 2.3 Wake Blockage

Any model (blockage) being tested in a wind tunnel has a region of disturbed flow behind it. This region is called as the wake and happens due to the detachment of the flow from the model. In this region, the mean velocity is comparatively lower than that at the far field condition. This results in a lower wake pressure. This effect increases with wake size hence is highest when large flow separation occurs. The wake blockage is responsible for increase in dynamic pressure, experienced by the model. Since the size of the wake is itself a function of the body shape and the ratio of the wake area to tunnel area, it is more intricate than solid blockage.

Maskell (Maskell, 1965), in his experiments, derived correction equations applied to flat plates stalled at the test section center. His theory is based on the principle of momentum balance. His procedure did not take into account, the solid blockage effects, but only those effects caused due to flow separation. He added a term to account for the increased velocity outside the wake. He obtained the total wake blockage corrections as

$$\varepsilon_{wb} = \frac{S}{4C} C_{d_o} + \frac{5S}{4C}\left(C_{d_u} - C_{d_i} - C_{d_o}\right)$$

For angles below separated flow, the last term, which is equal to $C_{d_s}$ vanishes.

## 3. CONCLUSIONS

In a wind tunnel, the flow conditions differ than in an airstream which is unbounded. In the wind tunnel tests to relate to real-life situations, wall corrections or blockage corrections are required and form an important part of the wind tunnel study. If not applied they can lead to distorted angle of attack, drag and pressure values.

As a standard practice, solid blockage is chosen in the range of 0.01-0.1 with 0.05 being typical or in other words the model frontal area should be 5% of the test-section area.

The total solid and wake blockage corrections may be summed as

$$\varepsilon_t = \varepsilon_{sb} + \varepsilon_{wb}$$

For certain unusual models that needs to be experimented in the wind tunnel for detecting blockage corrections, it is suggested to use,

$$\varepsilon_t = \frac{1}{4}\left\{\frac{model\ frontal\ area}{test-section\ area}\right\}$$

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